OBSERVATIONS of ANTINEUTRONS

W. A. Wenzel, LBNL, 10/28/05

I. Early Bevatron

II. Early PBar

III. Early NBar

IV. Some Elegant Evolutions

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The Early Bevatron:

I. The view from outside - a '55 conversation with Dick Feynman:

"There is no chance that the antiproton does not exist. You guys at Berkeley just love to throw equipment at your accelerators."

II. But inside the Rad Lab - at the early Bevatron:

- **Lofgren held active weekly Scheduling Meetings with fast turnover of experiments. Bill Galbraith (visitor from RHEL) remembered: "....free discussion among experimenters......fair shares for all....... efficient shop facilities......very good supporting services..... apparatus of high standards, but......." there were limitations -**
- **Shortages in electronics and very small magnets.**
- **"Midnight Requisitioning" - electronics was "traded" almost hourly. Experimenters encouraged to - think small and prepare to share -**
- **Initially the absence of new equipment and operating funds was inconsistent with the large (>9M$) Bevatron construction budget.**

III. Ed Lofgren created (1/54) an informal committee to set priorities for new equipment. First choice: Larger Dipole(s). Designed by Bill Salsig (Bevatron Mechanical Engineering), two @ 3.2Tm were ready in 1955.

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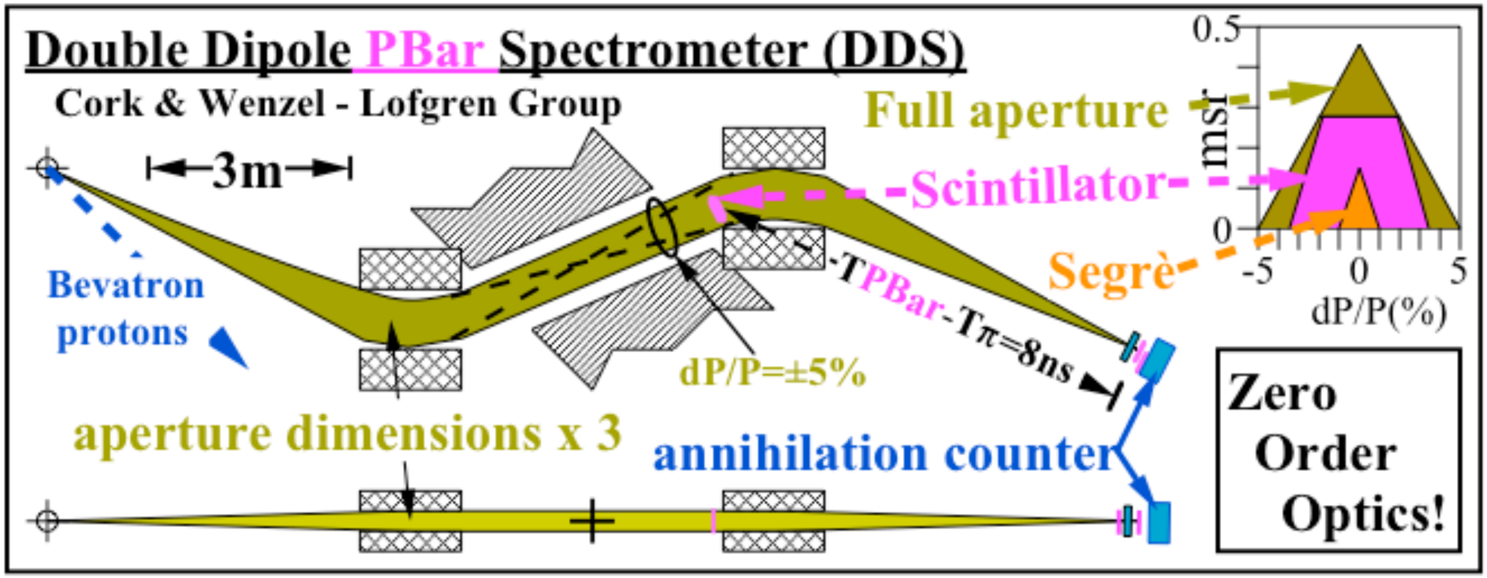
Double Dipole PBar Spectrometer

Anticipating PBar and the arrival of two large Bevatron dipoles, Cork and Wenzel considered a **Double Dipole Spectrometer** of large aperture, with PBar ID by ToF, threshold Cherenkov and annihilation. The **n=1/2** field gradient (Bevatron and Cosmotron) requires a 1.4 degree poletip slope.



Some reasons DDS never happened:

1. **Too much work for two; Lofgren group colleagues, Joe Murray & Nahmin Horwitz, wanted a simpler plan. [Was Feynman right?!]**
2. **The Segrè Group wanted both dipoles for their pbar spectrometer.**
3. **Carol and I wanted to get married.**

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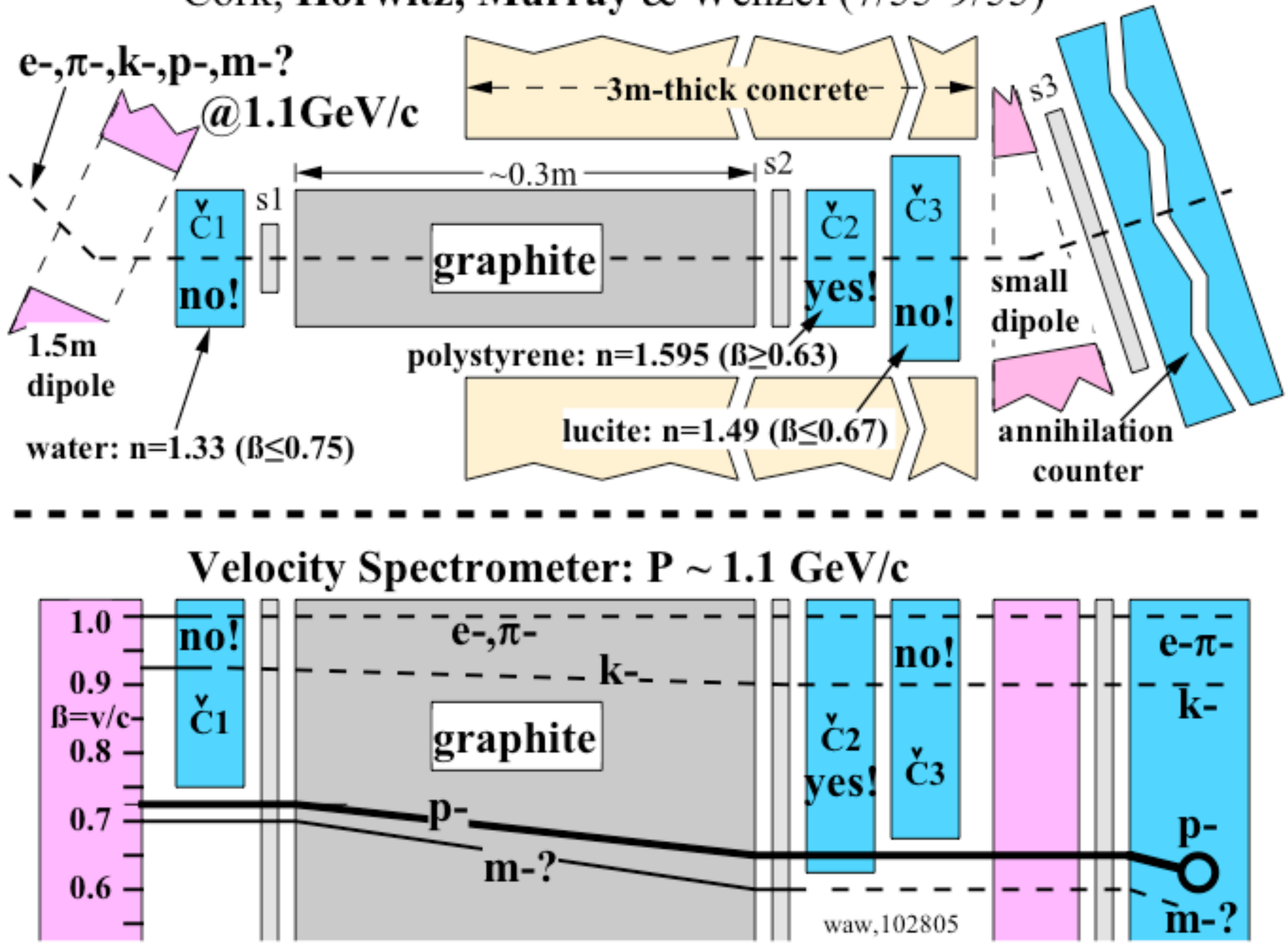
Cherenkov PBar Spectrometer

Cork, **Horwitz, Murray** & Wenzel (7/55-9/55)



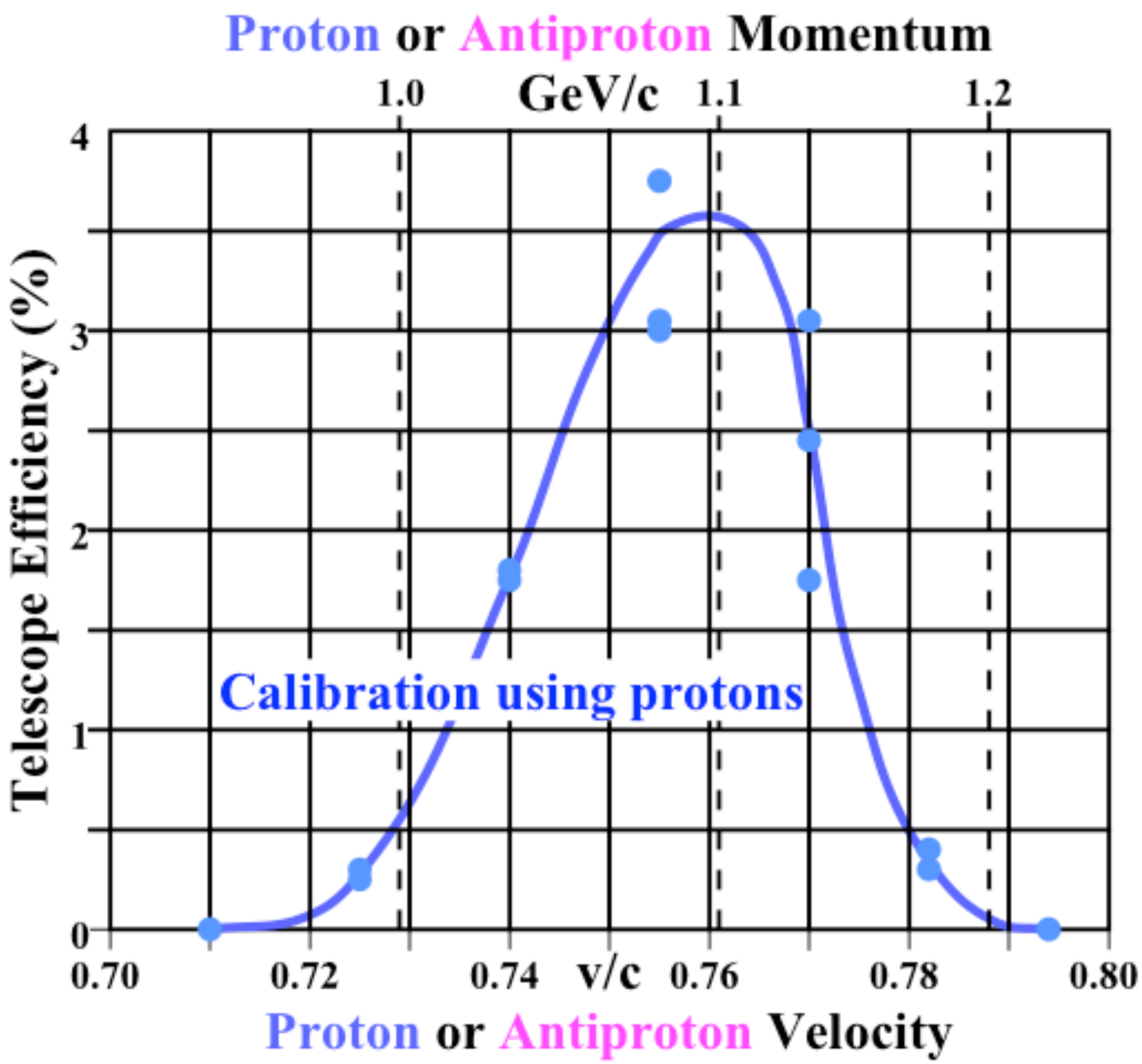
Antiproton Search - Bevatron-88, August 10, 1955

Joseph Murray, Nahmin Horwitz, Bruce Cork, William Wenzel, John Brabant and Roger Wallace.

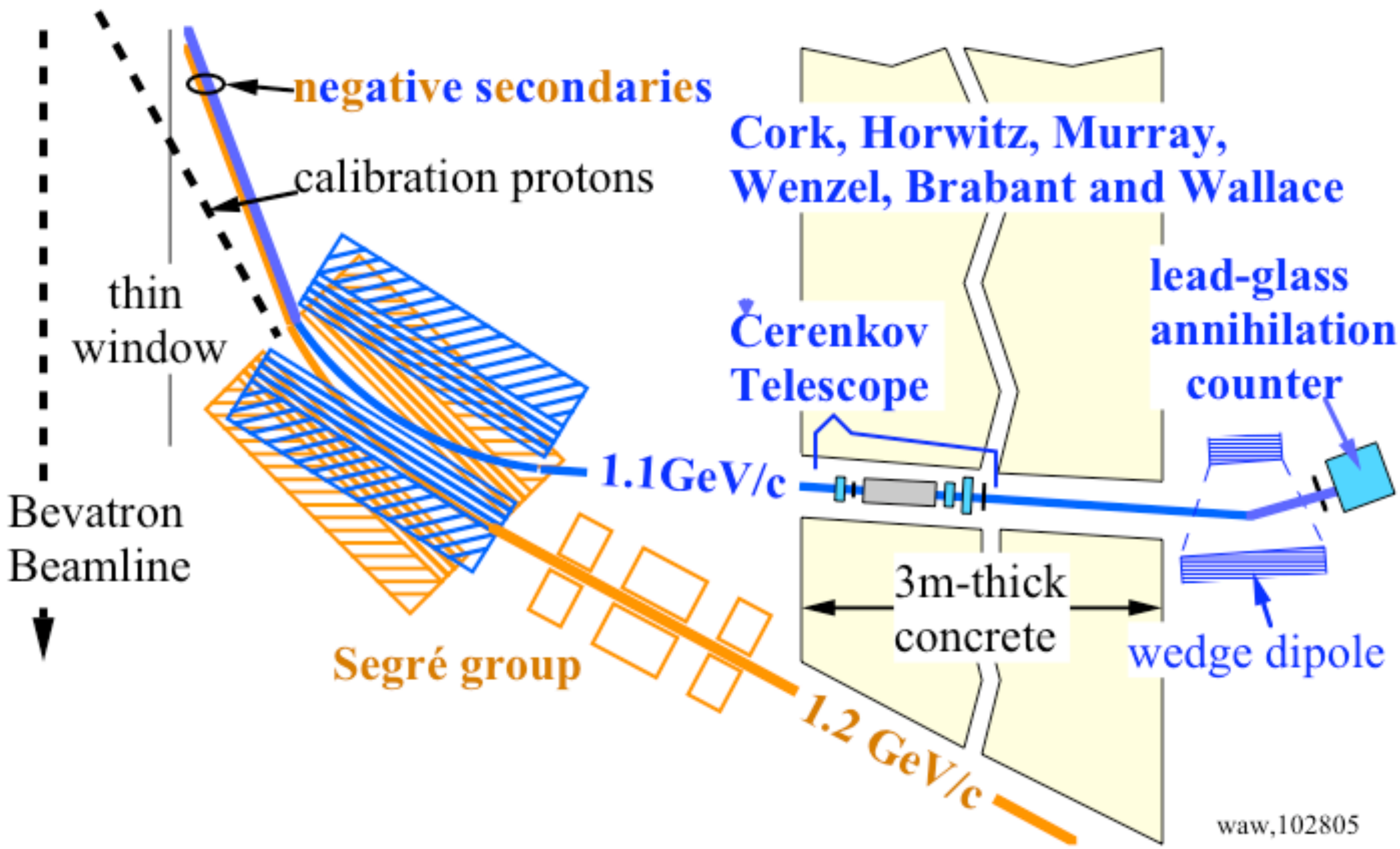
1. Beam was shared with the Segre group, alternating in the use of the first dipole .

2. The efficiency was measured relative to the flux incident on the first counter.

3. "Approximately two hours were devoted to Antiproton Search. During this time roughly 400,000 negative pions were incident on the front aperture of the telescope, and one signature was obtained. The lead glass counter pulse associated with the signature, however, was only twice the height of pulses produced by negative pions."



West Platform PBars (July-August '55)

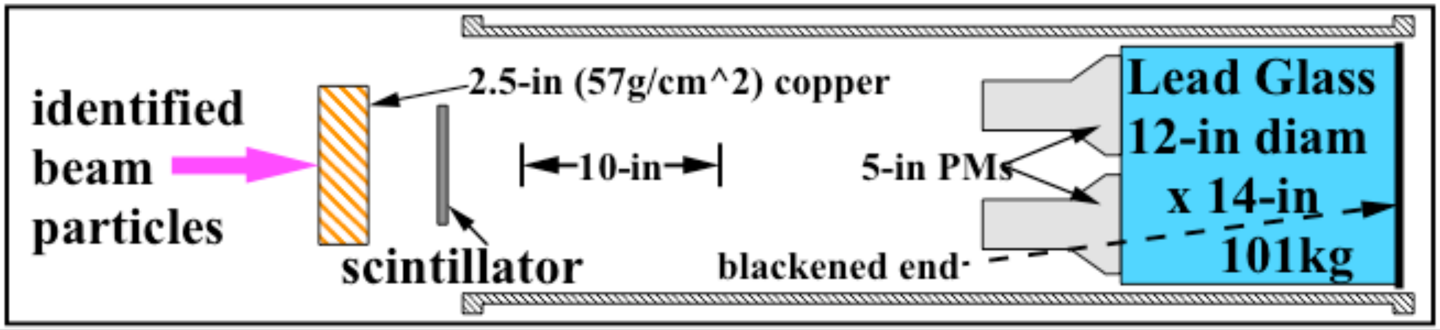


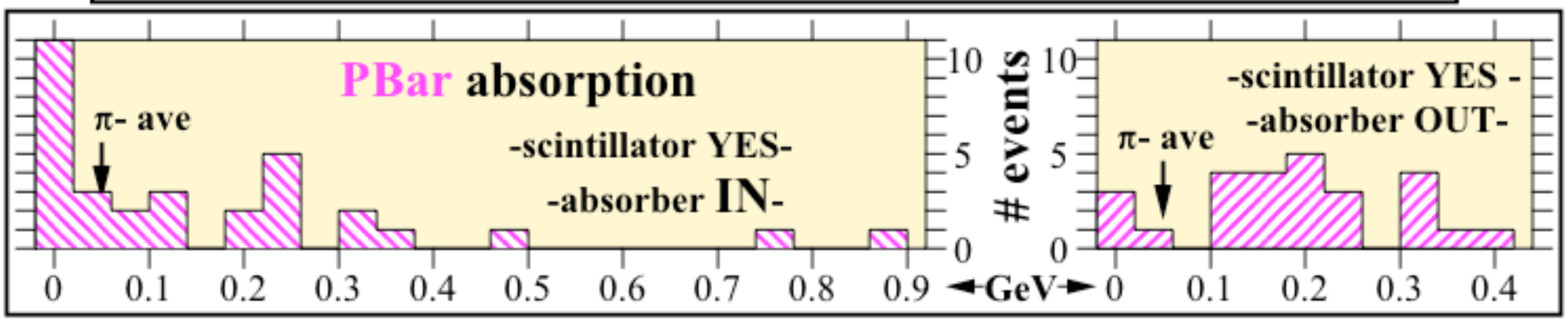

September, 1955
Segrè Beamline
Lofgren-Moyer Electronics
Burt Moyer
Bruce Cork
Herb Steiner
Owen Chamberlain

Lead Glass Annihilation Detector A (Oct. - Nov. '55)

Brabant, Cork, Horwitz, Moyer, Murray, Wallace & Wenzel. Phys Rev 101, 498 (1956)

PBar mass selection by Chamberlain, Segrè, Wiegand & Ypsilantis.





I. Lead Glass as in Bevatron-88 PBar run of Lofgren-Moyer.

* Calibration - pass-through (vertical) cosmic ray muons.
* Blackened end of increased ratio of annihilation/pass-through π- signals. **But:**
* Total light signal from PBars and solid angle of lead glass were both reduced.

II. Observed large cross section for PBar absorption:

* Lead glass signal ratio for copper absorber in/out gave cross section 1.7±0.7 'geometric.'
* PBars passing through lead glass gave 1.9±0.7 'geometric.'
* I had another visit from Edward Teller.

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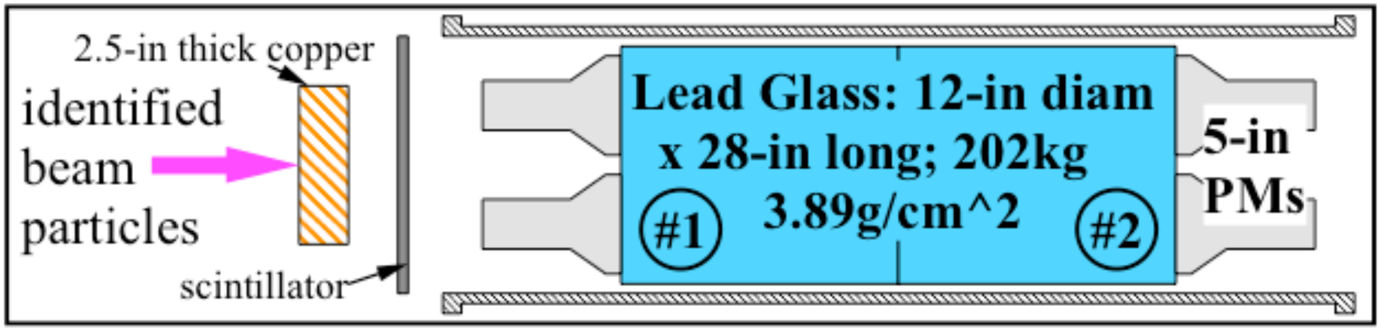
Lead Glass Annihilation Detector B (Dec.'55-Feb.,'56)

Brabant, Cork, Horwitz, Moyer, Murray, Wallace & Wenzel. Phys Rev 102, 1622 (1956)

PBar mass selection by Chamberlain, Segrè, Wiegand & Ypsilantis.



I. Better confinement of annihilation than in A.

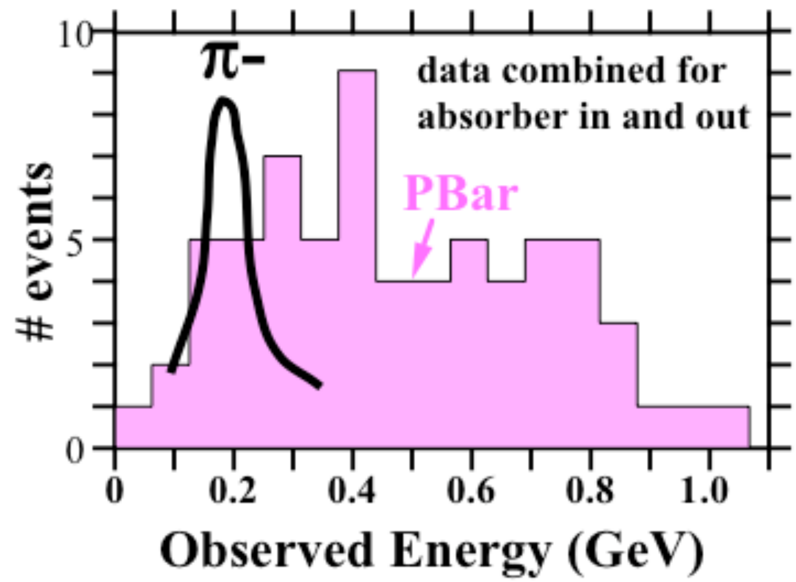
II. Better light collection and larger solid angle.

III New measurements again gave (large) cross sections for PBar absorption.

Copper absorber in/out gave 1.5±0.5 geometric.

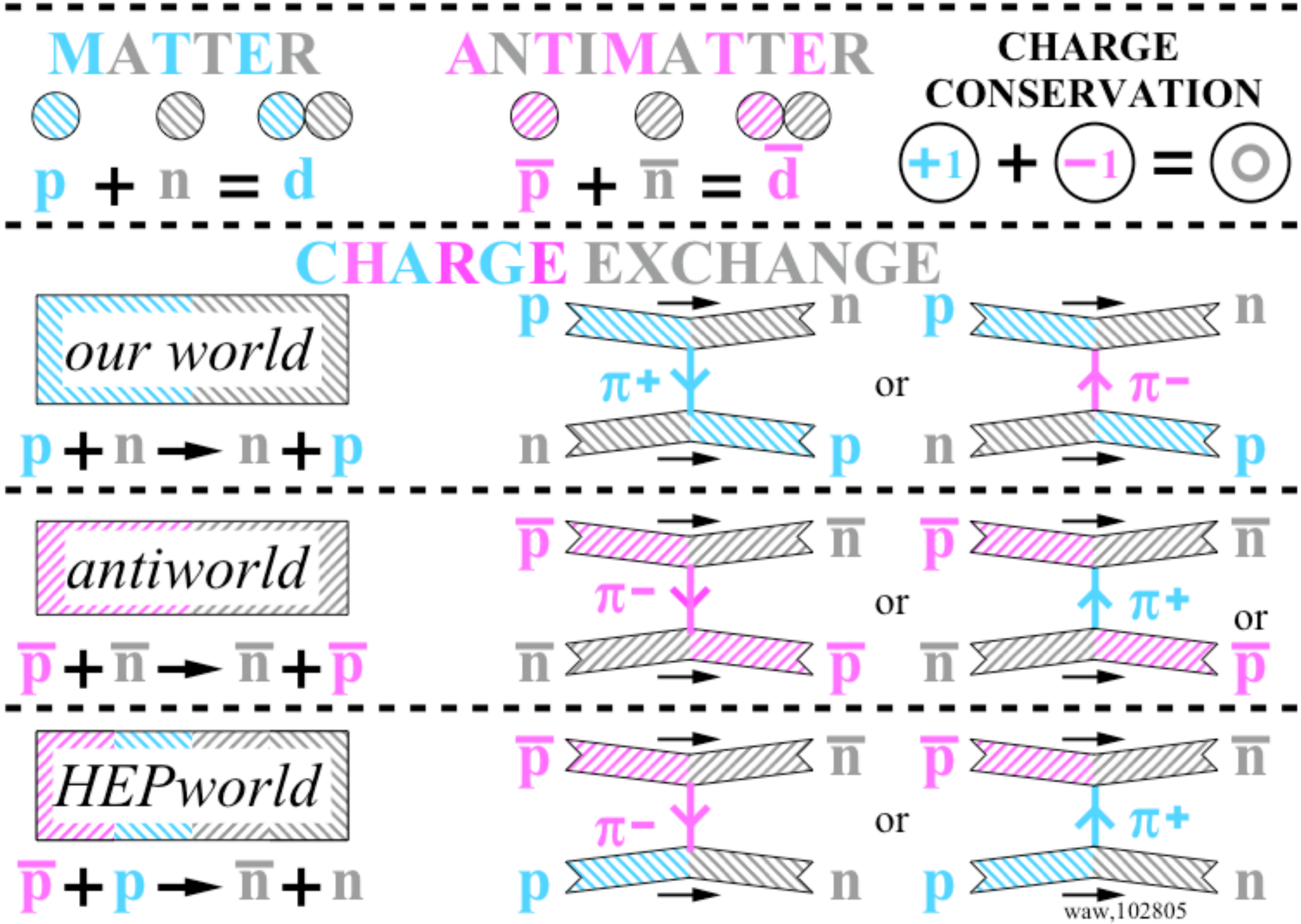
Slowing PBars are seen not to reach counter #2; so the absorption cross section is consistent with twice 'geometric' at 400-500 MeV and 3-4 times 'geometric' at 150-400 MeV,

where r(geom)=1.25xA^(1/3)x10^(-13)cm.

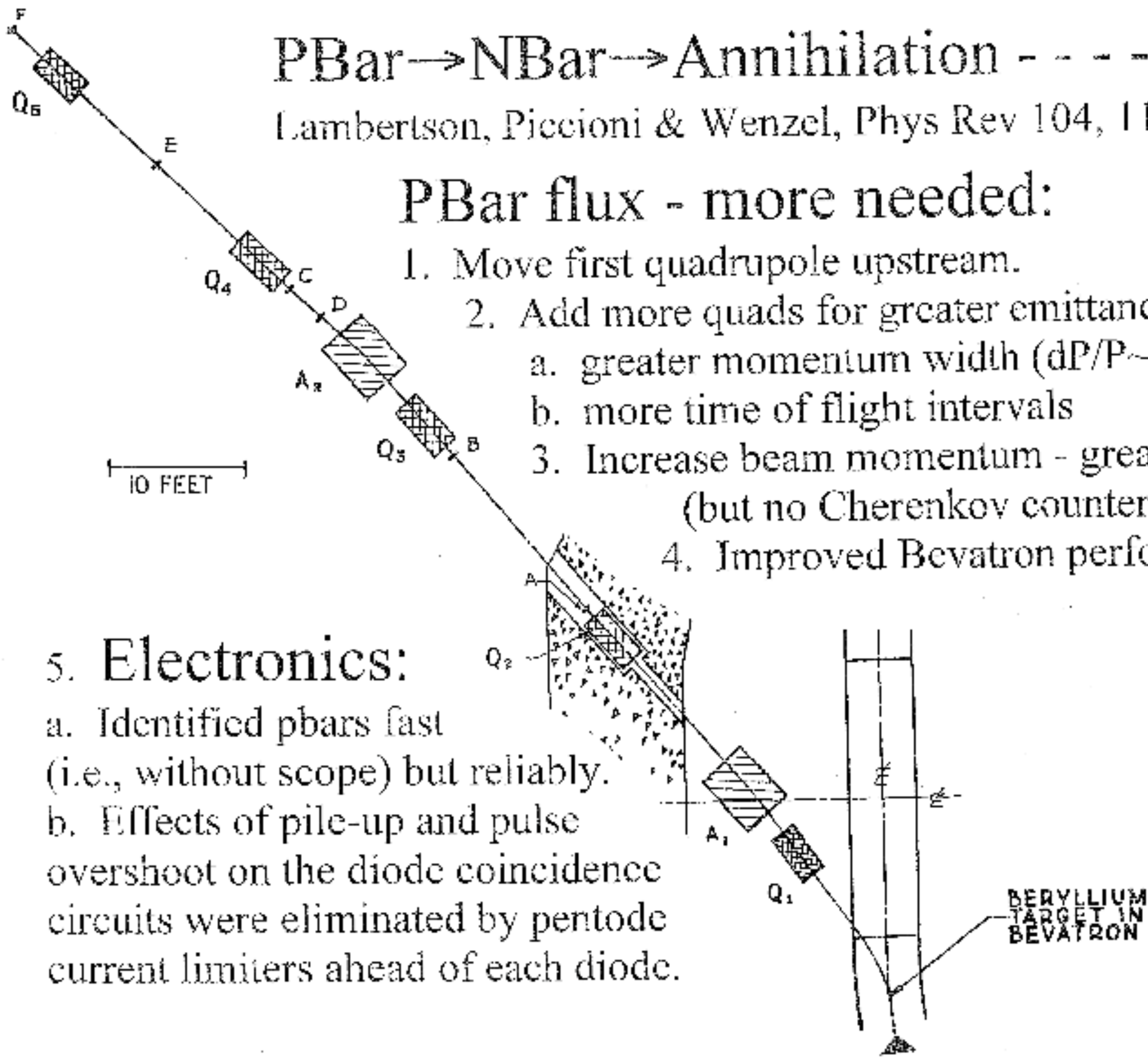


IV. The search for NBar by charge exchange in the copper absorber was unsuccessful - the small solid angle (1/20 sterad.) was a limitation; but also - **not enough PBars!**

Some Expected Symmetries in Particle Physics



PBar→NBar→Annihilation - - - - - Cork, Lambertson, Piccioni & Wenzel, Phys Rev 104, 1195 (1956)



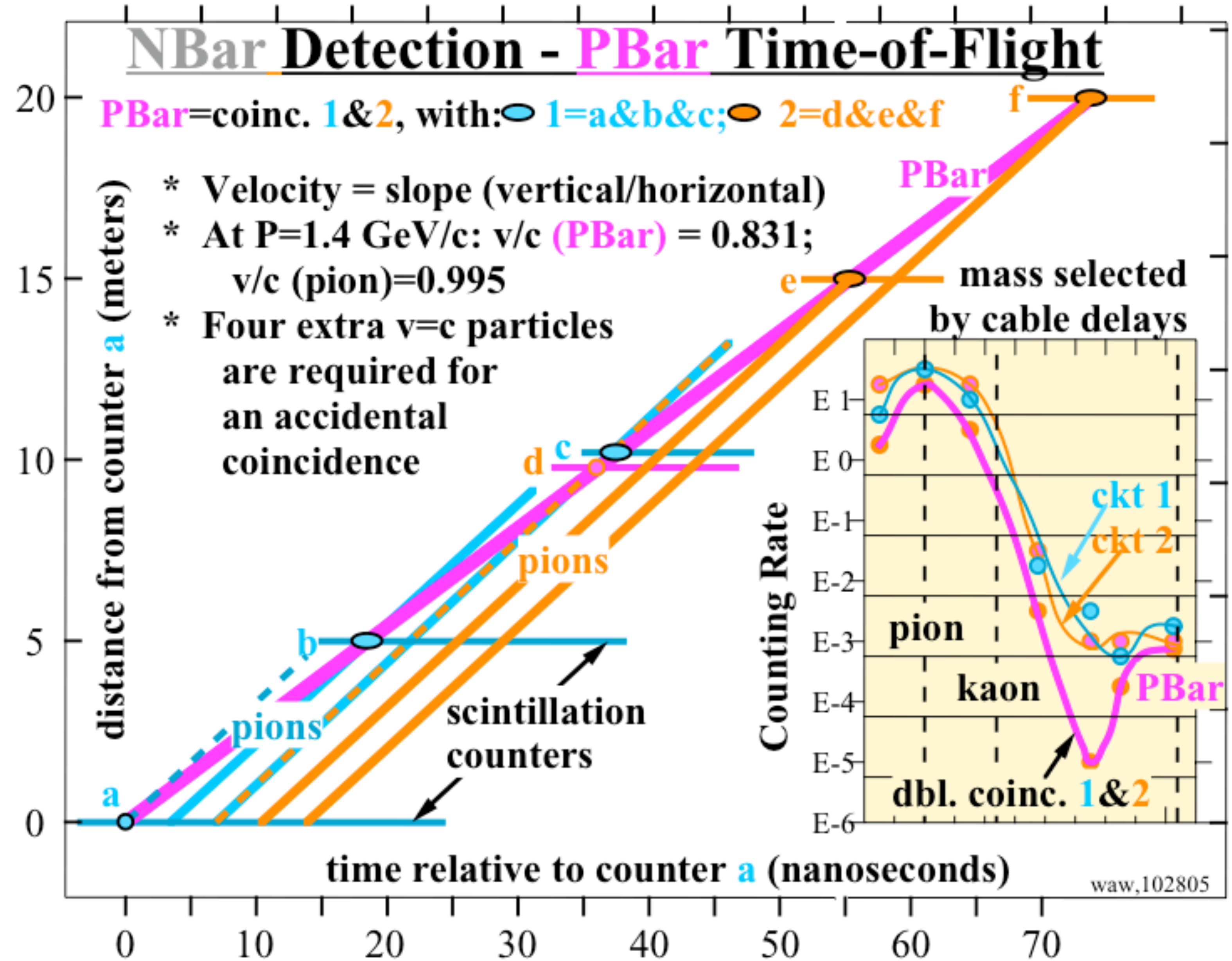
PBar flux - more needed:

1. Move first quadrupole upstream.
2. Add more quads for greater emittance and:
   a. greater momentum width (dP/P~10%)
   b. more time of flight intervals
3. Increase beam momentum - greater yield (but no Cherenkov counter in beam)
4. Improved Bevatron performance.

5. Electronics:

a. Identified pbars fast (i.e., without scope) but reliably.

b. Effects of pile-up and pulse overshoot on the diode coincidence circuits were eliminated by pentode current limiters ahead of each diode.



NBar Detection - PBar Time-of-Flight
PBar=coinc. 1&2, with: 1=a&b&c; 2=d&e&f
* Velocity = slope (vertical/horizontal)
* At P=1.4 GeV/c: v/c (PBar) = 0.831;
v/c (pion)=0.995
* Four extra v=c particles
are required for
an accidental
coincidence
mass selected
by cable delays
distance from counter a (meters)
time relative to counter a (nanoseconds)
scintillation
counters
pions
pions
PBar
a
b
c
d
e
f
0
5
10
15
20
0
10
20
30
40
50
60
70
Counting Rate
E 1
E 0
E-1
E-2
E-3
E-4
E-5
E-6
pion
kaon
PBar
ckt 1
ckt 2
dbl. coinc. 1&2
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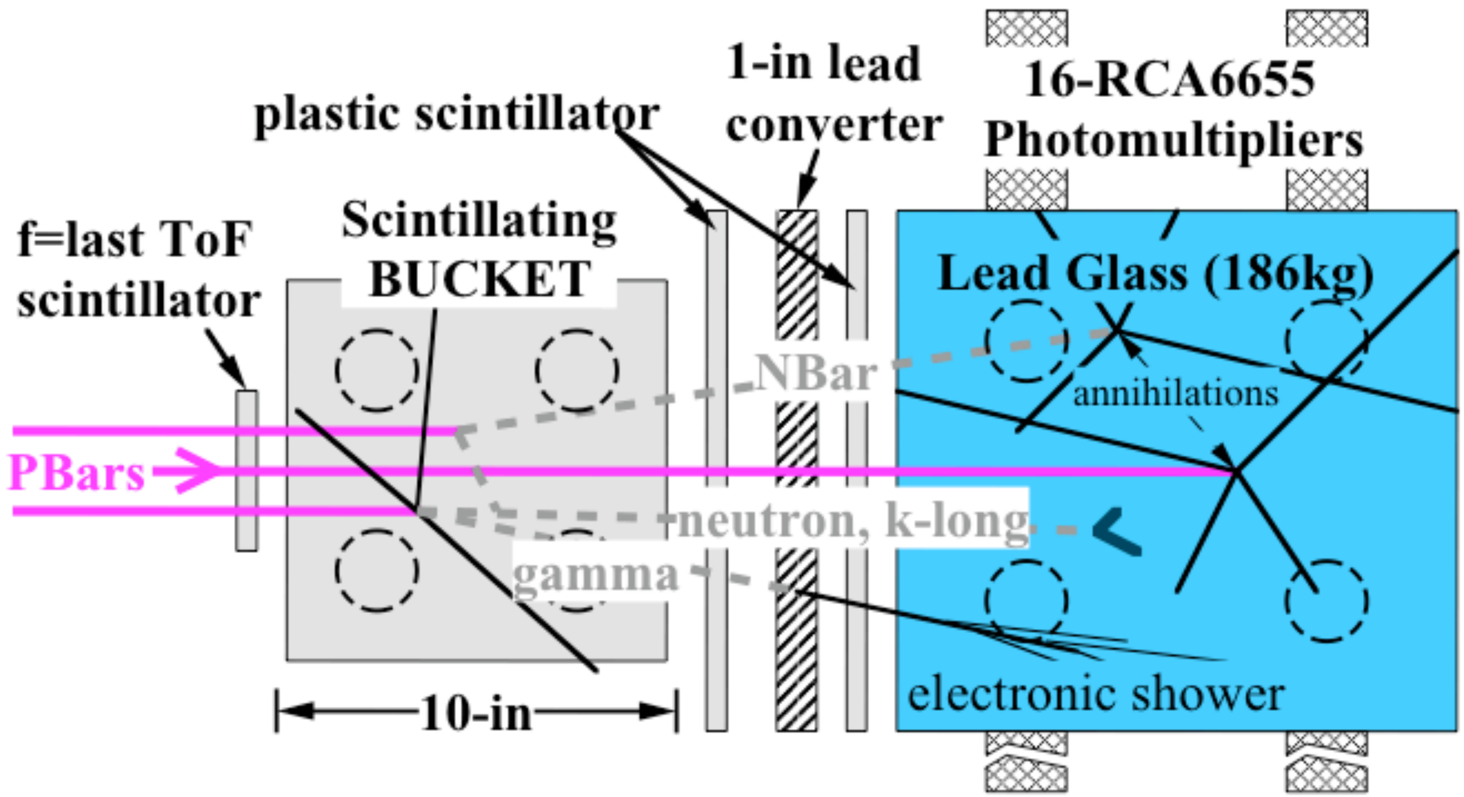
NBar Detection - Experimental Set-up

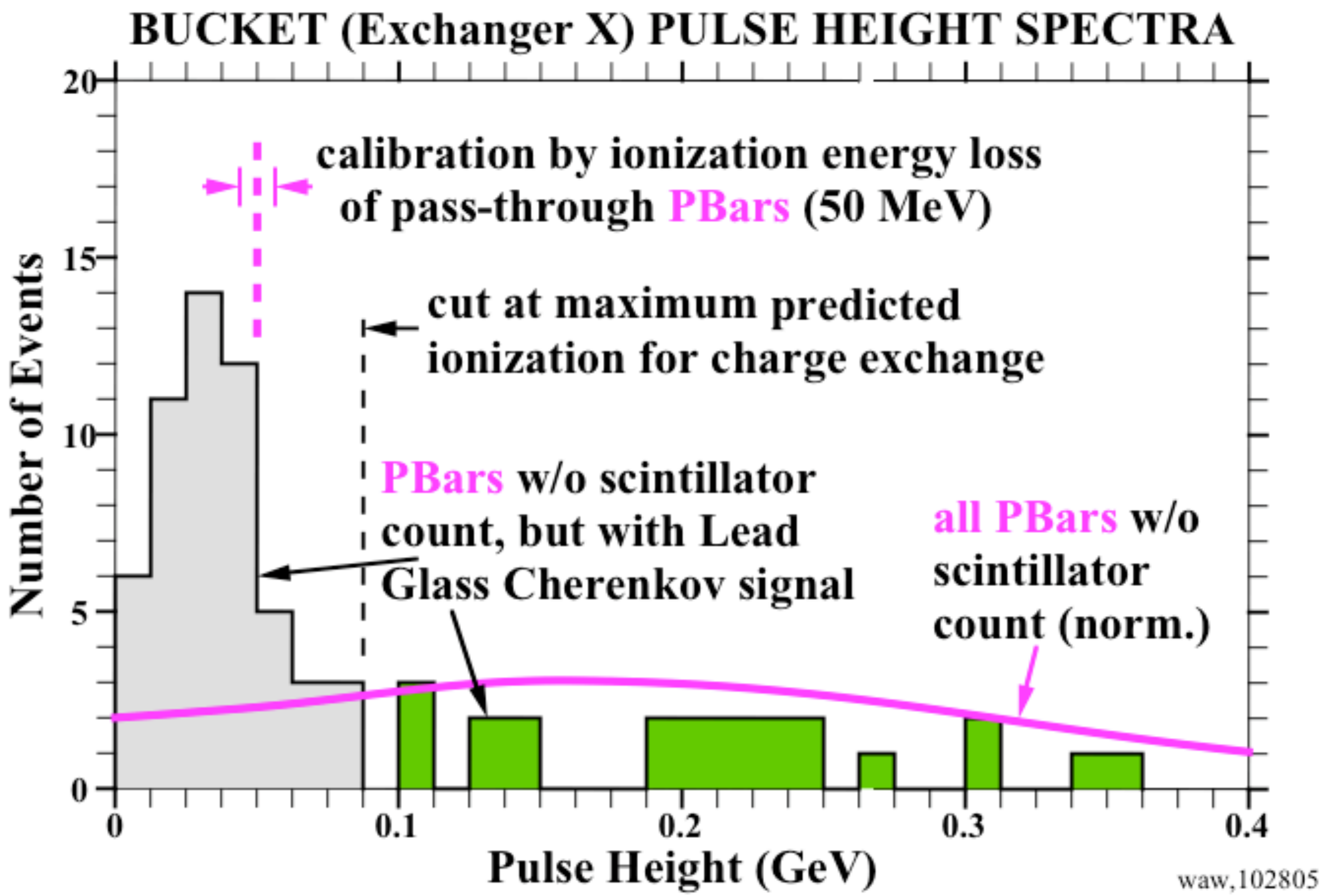
Cork, Lambertson, Piccioni & Wenzel, Phys Rev 104, 1193 (1956)



* Besides charge exchanging into an antineutron, PBar can annihilate in the BUCKET, not always with a big pulse. Even so, false annihilation signals from neutral BUCKET secondaries are avoided because:
* Gammas (pizero decay) are efficiently converted into electrons by lead.
* Neutrons and k-longs don't give large signals in lead glass.

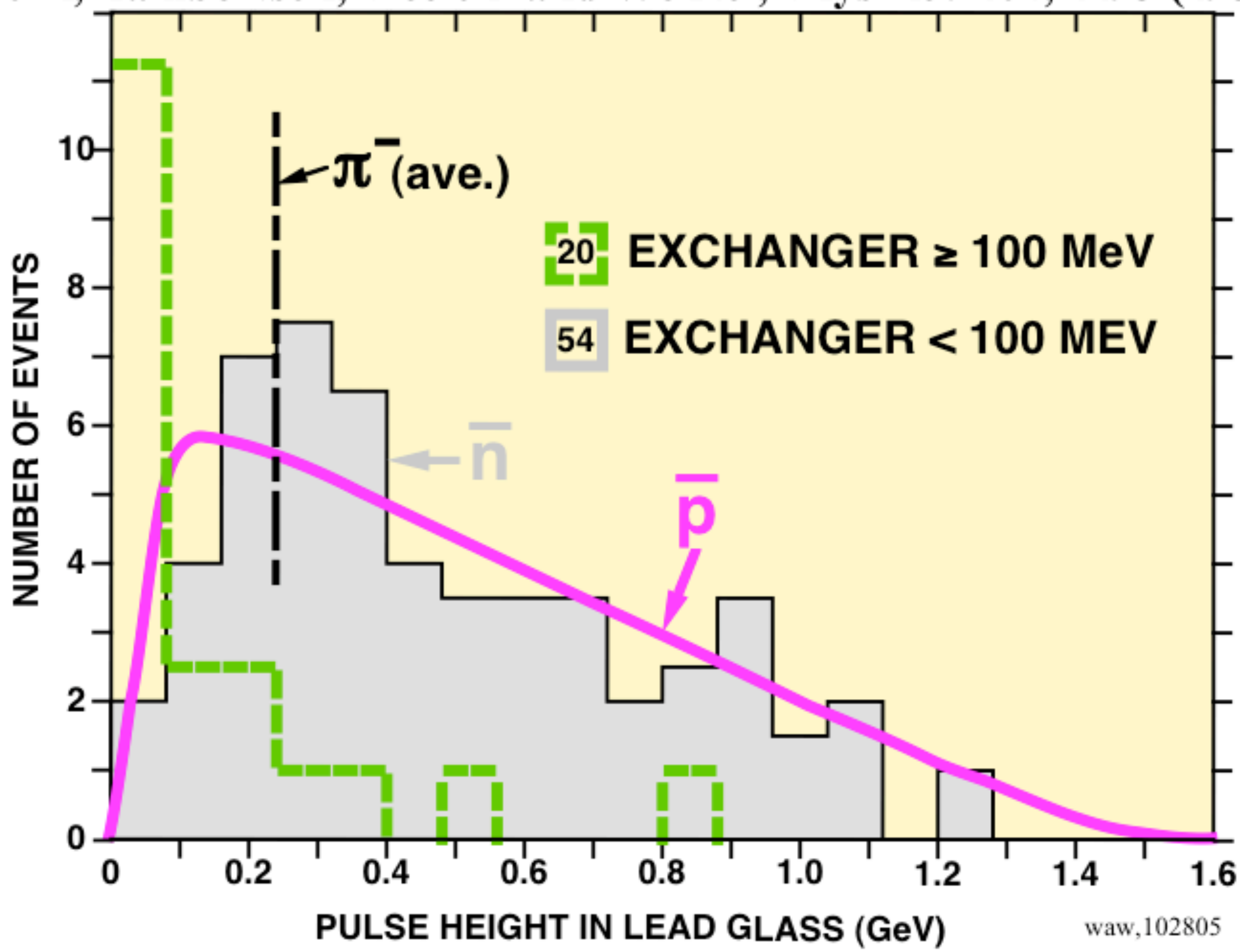
NBar Detection - Bucket

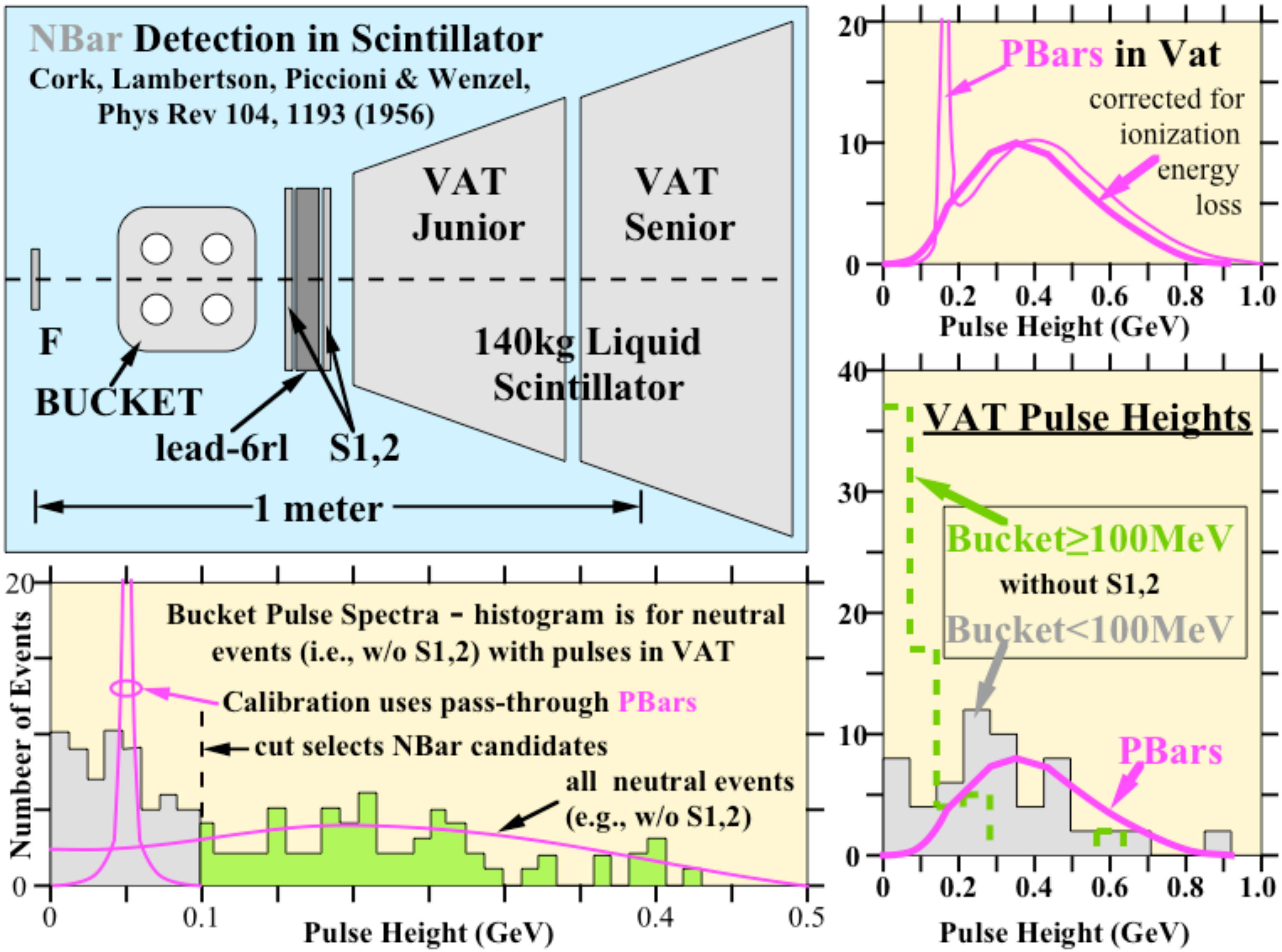
Cork, Lambertson, Piccioni & Wenzel, Phys Rev 104, 1193 (1956)



NBar Detection - Pulse Height in Lead Glass

Cork, Lambertson, Piccioni and Wenzel, Phys Rev 104, 1193 (1956)




NBar Detection in Scintillator
Cork, Lambertson, Piccioni & Wenzel,
Phys Rev 104, 1193 (1956)
F
BUCKET
lead-6rl
S1,2
VAT Junior
VAT Senior
140kg Liquid Scintillator
1 meter
PBars in Vat
corrected for ionization energy loss
Pulse Height (GeV)
VAT Pulse Heights
Bucket≥100MeV
without S1,2
Bucket<100MeV
PBars
Pulse Height (GeV)
Bucket Pulse Spectra - histogram is for neutral events (i.e., w/o S1,2) with pulses in VAT
Calibration uses pass-through PBars
cut selects NBar candidates
all neutral events (e.g., w/o S1,2)
Numbeer of Events
Pulse Height (GeV)

Bruce Cork   Oreste Piccioni   Glen Lambertson   Bill Wenzel

NBar Celebration:

<u>**The Daily Californian**</u> **(9/14/56). "First it was the positive electron, then the antiproton, now it looks like the antineutron has been found. The cycle is now complete. A world of antimatter is now considered possible...Now that the existence of the last antiparticle is a reasonable certainty, an interesting subject for science fiction addicts is the possible existence of an 'anti-world'."**

<u>**Time Magazine**</u> **(9/24/56). "Like philatelists filling the last empty space in a series of cherished stamps, physicists have now found the last subatomic particle that is needed to make the universe neatly and electrically symmetric."**

<u>**Darwin Society, Science Section**</u>, Shrewsbury, England (10/17/56)

Dear Sir, We in **England** have been following eagerly the scanty reports of your recent discovery of the <u>**antineutron**</u>, on which we offer our hearty congratulations.

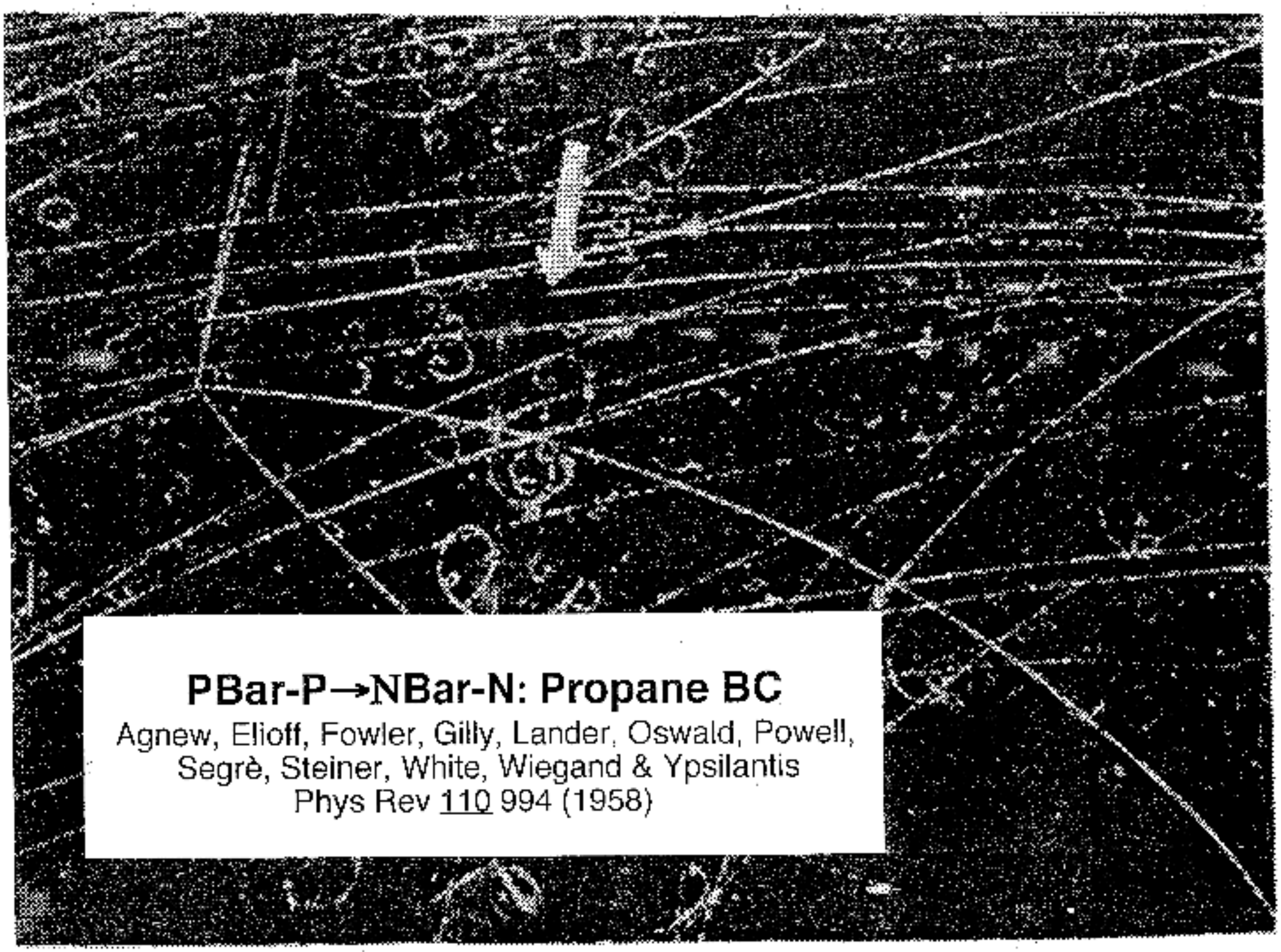
Next week one of Britain's leading nuclear physicists, **Sir James Chadwick**, is giving a lecture to the above society, during the course of which he is expected to talk about the <u>**neutron**</u>. We felt that it would be fitting if a lecture could be given on the discovery of the <u>**antineutron**</u>, and on its importance in nuclear physics. In view of this, we should be extremely grateful for any information that you could give us on this subject, especially of the fairly elementary type. I appreciate that a great deal of the details must be secret, but any information that you could supply would be extremely acceptable.

Yours sincerely,

M.W.Cross, SECRETARY

Bruce Cork replied that none of the material was classified; he sent them our new Phys Rev paper.

N.B. This talk by Chadwick was given 24 years after his discovery of the neutron (and Anderson's of the **positron**), **less than half the elapsed time from the discovery of the antineutron til now.**



PBar-P→NBar-N: Propane BC

Agnew, Elioff, Fowler, Gilly, Lander, Oswald, Powell, Segrè, Steiner, White, Wiegand & Ypsilantis

Phys Rev 110 994 (1958)

An Experimental Future for NBars? PBars were easier!

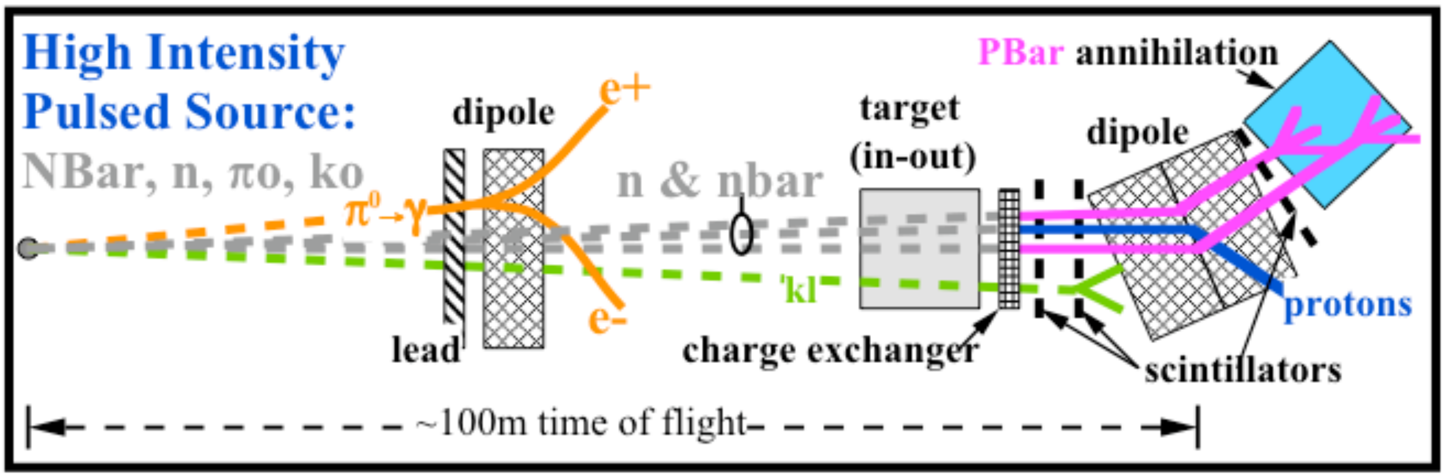
- 1957-8: Anticipating PS (1959) and AGS (1961), a study group appointed by McMillan explored possiblities for a new **proton** accelerator of High Intensity @ 15-30 GeV

  Singles rates of π- in **PBar** beamlines would be too high for scintillation counters..so...

- **What about NBar - PBar Role Reversal? - W.N.Hess (~1957)**

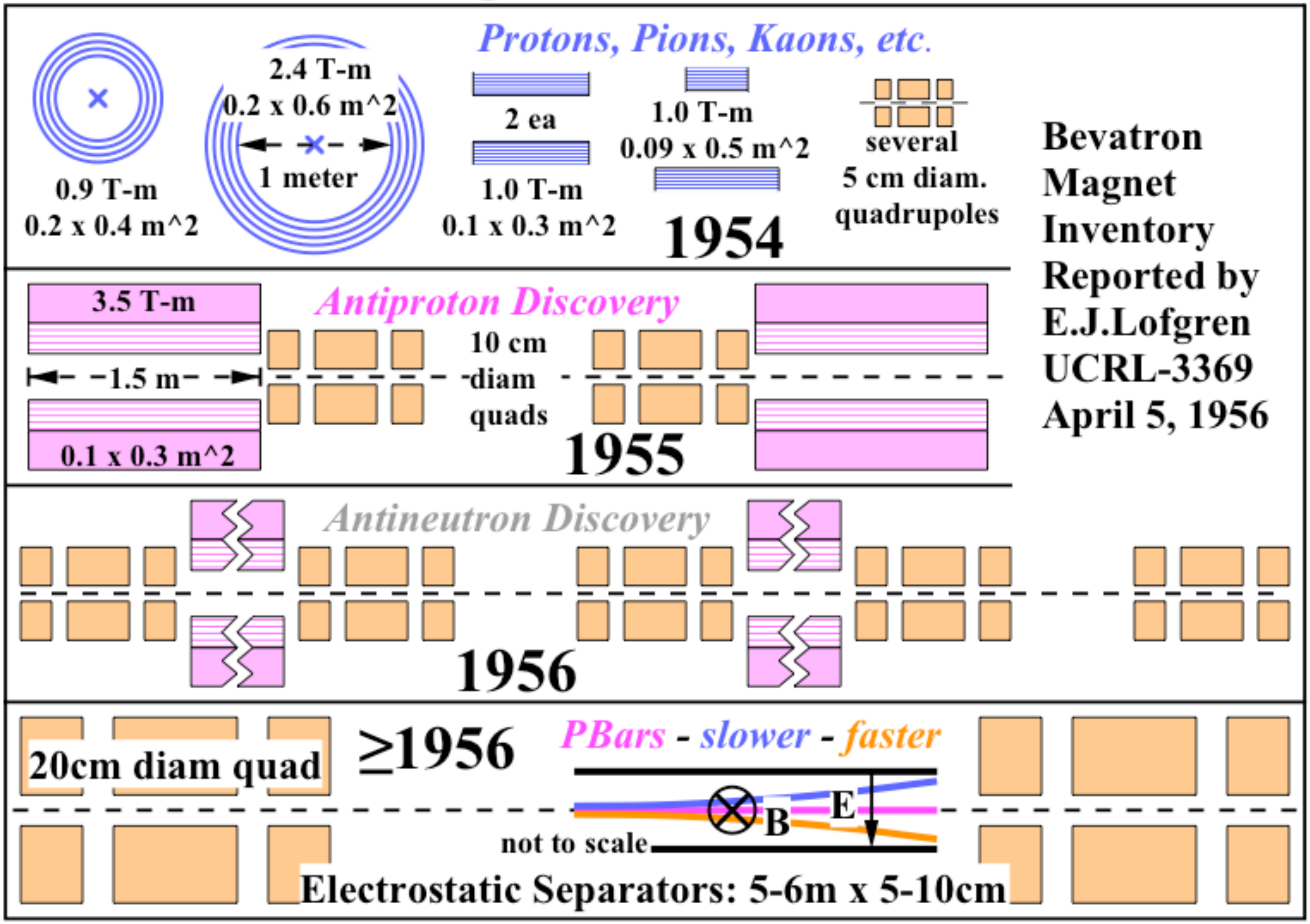
  NBar beam for high statistics measurements of **antiparticle** cross sections (P≤2GeV/c):

  1. Small counting rates from **neutrals** in beamline!
  2. Filter **pizero gammas** with **lead** followed by a **magnet** (repeat as needed).
  3. "Elastic" charge exchange - NBar to **PBar** identifies NBar direction.
  4. Time of flight from pulsed source gives nbar momentum, which must match that of 'elastic' **PBars**, as measured using a **magnet and scintillators**.
  5. High statistics measurements of charge exchange, elastic and total cross sections.



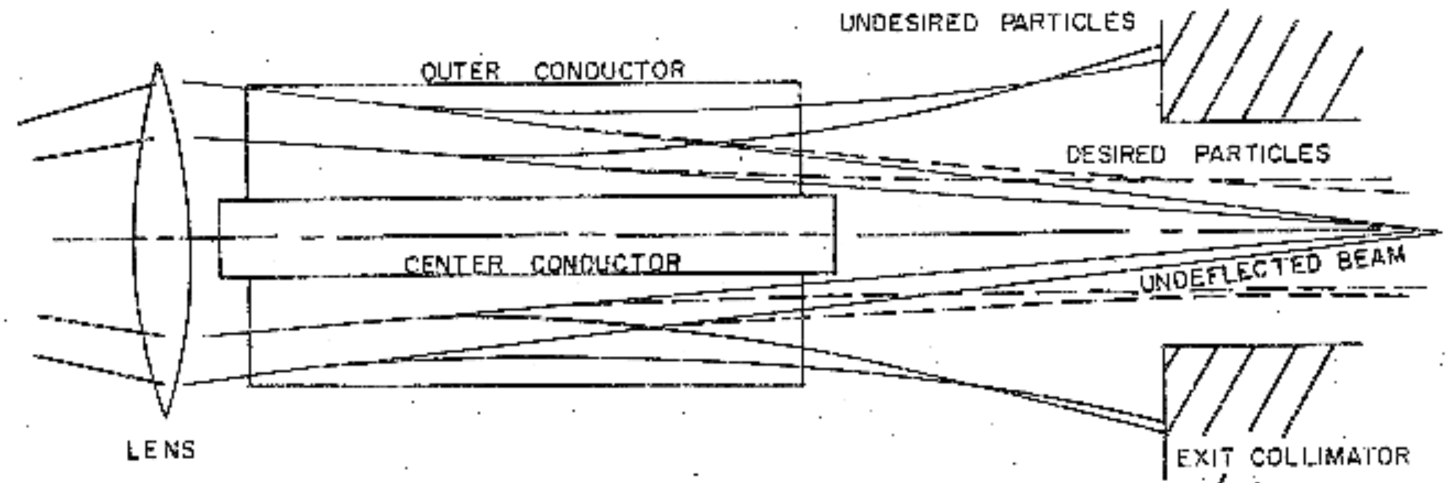
- Rad Lab studies for new accelerators soon turned to the High Energy frontier, but other developments reduced the beam contamination of **PBar** beams. waw,10/28/05

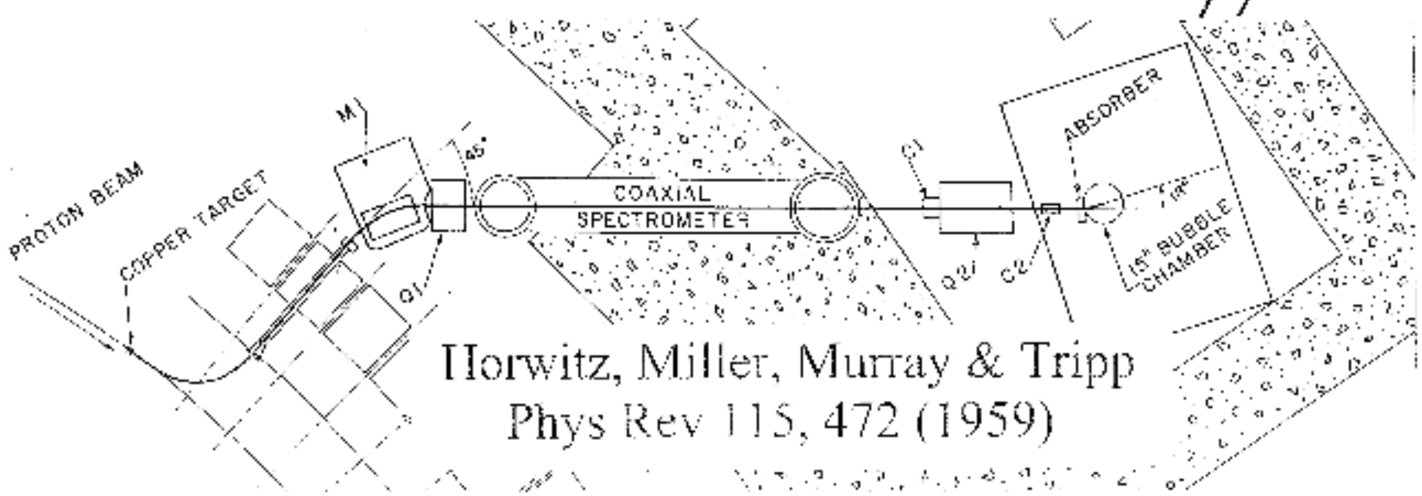
Bevatron Magnet Evolution: 1954-1960



COAXIAL ELECTROSTATIC SEPARATOR

Murray, Horowitz





Horwitz, Miller, Murray & Tripp

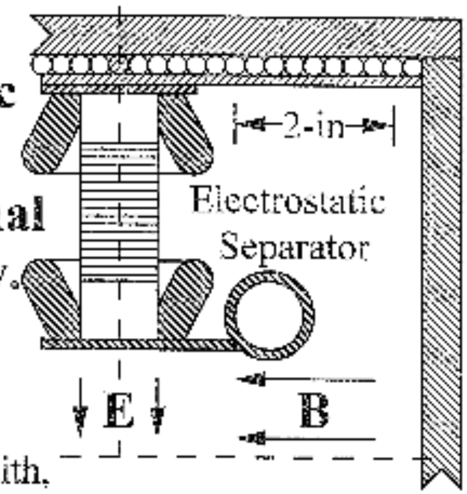
Phys Rev 115, 472 (1959)

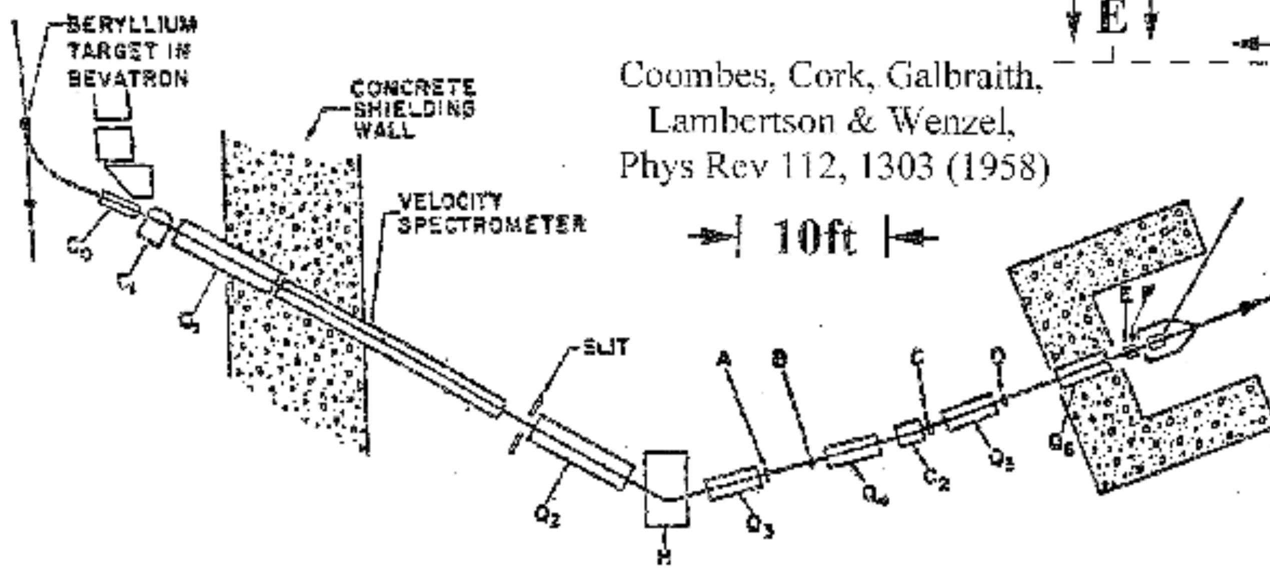
Parallel Plate Separators ≥1956

Lofgren Grp - Cork, Lambertson, Wenzel & Zajec

angular separation: $\propto \sim (EL/P)(c/V-c/V_o)$

*** For PBar and other counter experiments, the final state detectors were evolving greatly in complexity. They benefitted from reduced background rates.**



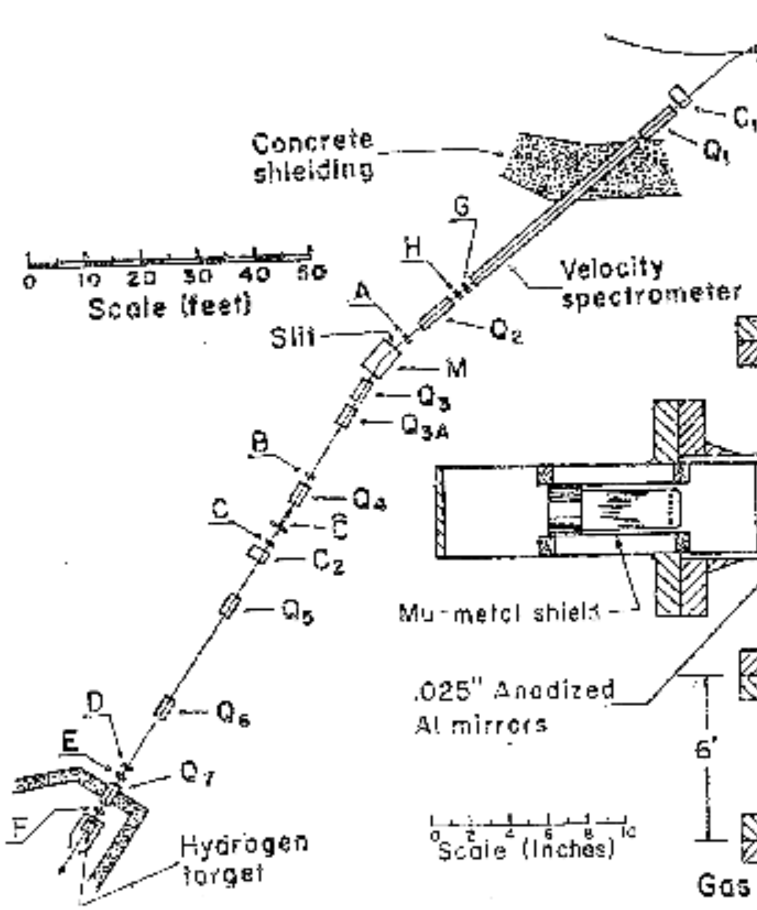


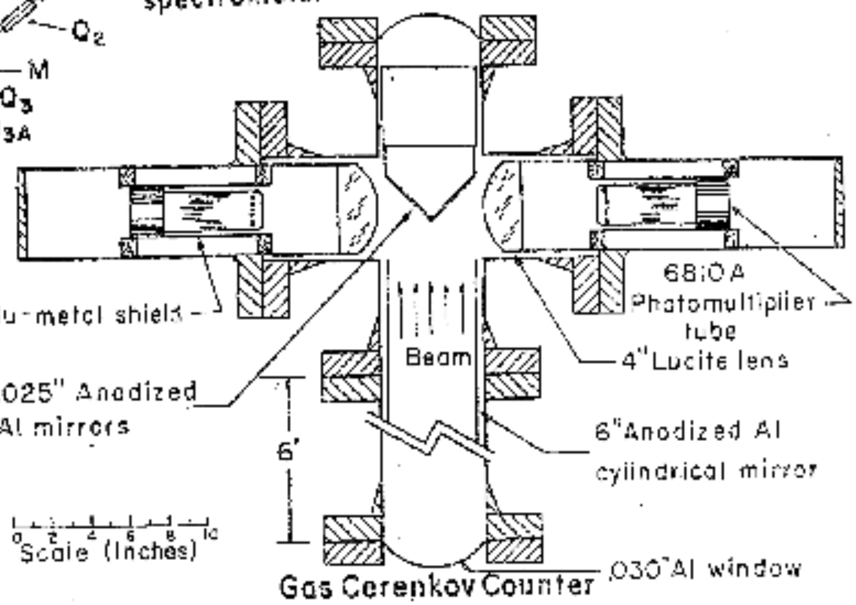
Coombes, Cork, Galbraith, Lambertson & Wenzel, Phys Rev 112, 1303 (1958)

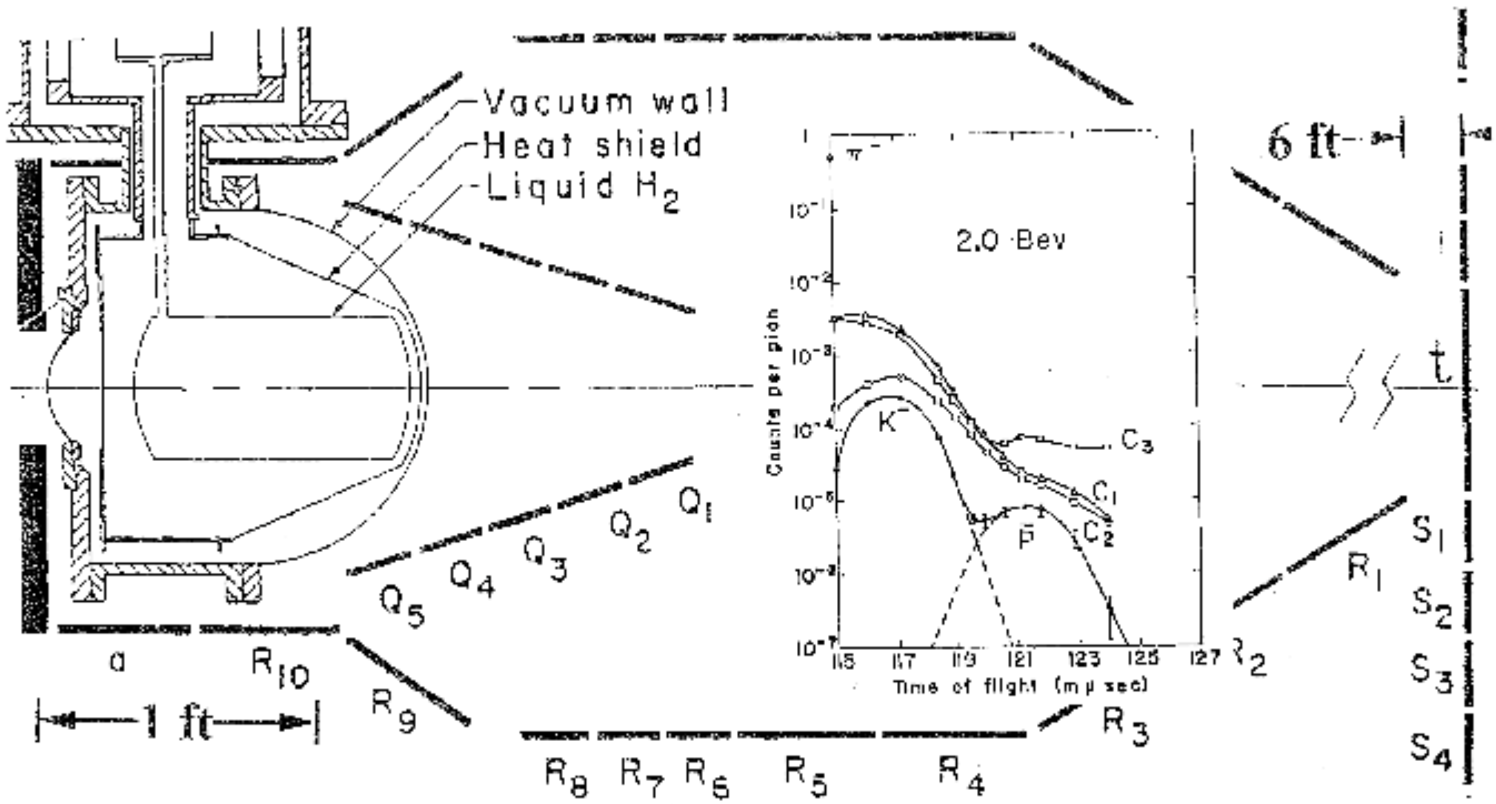
*** Bubble Chambers gained the most overall from separated beams: Experimenters (Eberhard, Good, Ticho, Button et al) studied and corrected magnet aberrations, higher multipoles, etc.**

*** Hot cathodes (Joe Murray) doubled the achievable voltage.**

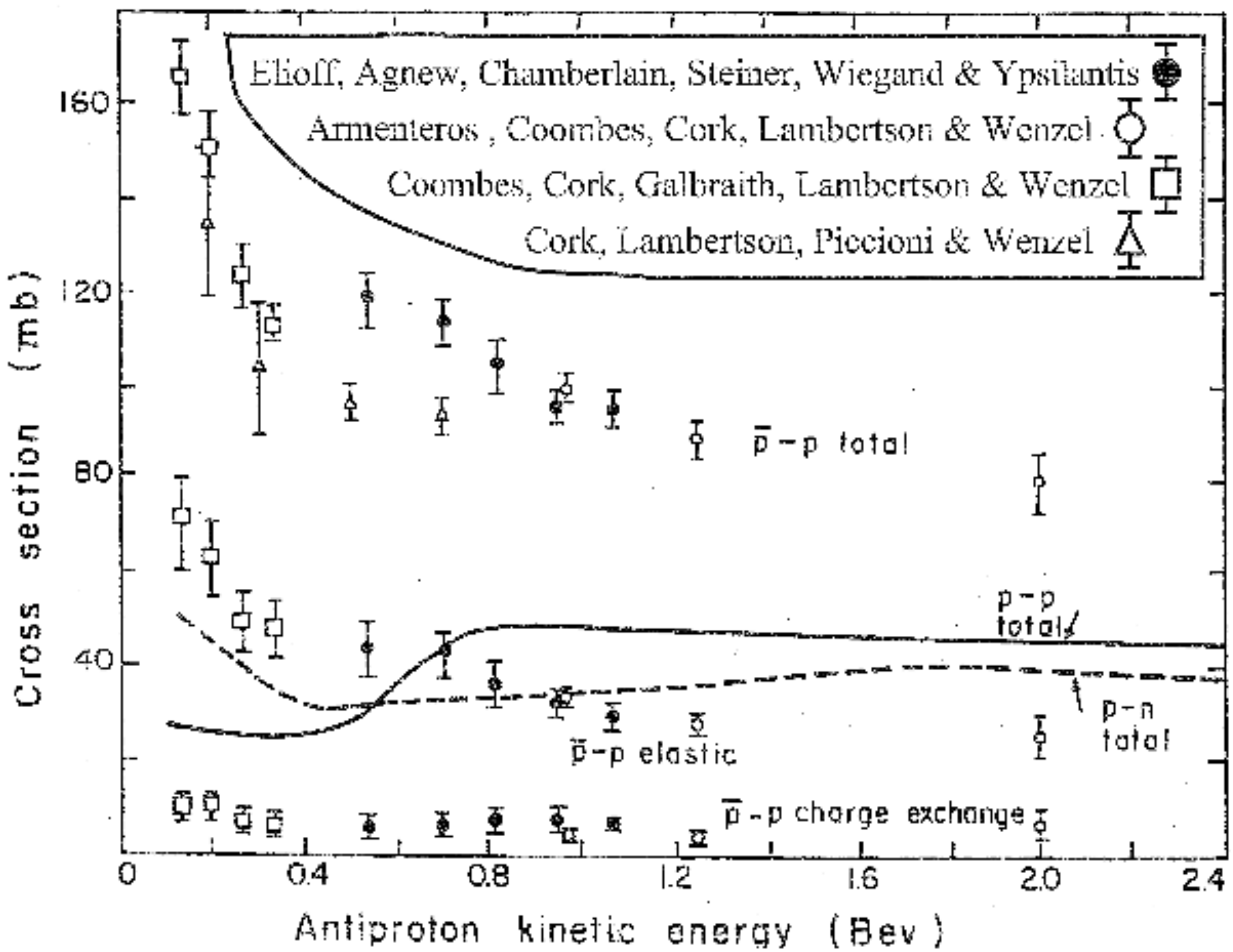
Armenteros, Coombes, Cork,
Lambertson & Wenzel
Phys Rev 119, 2068 (1960)



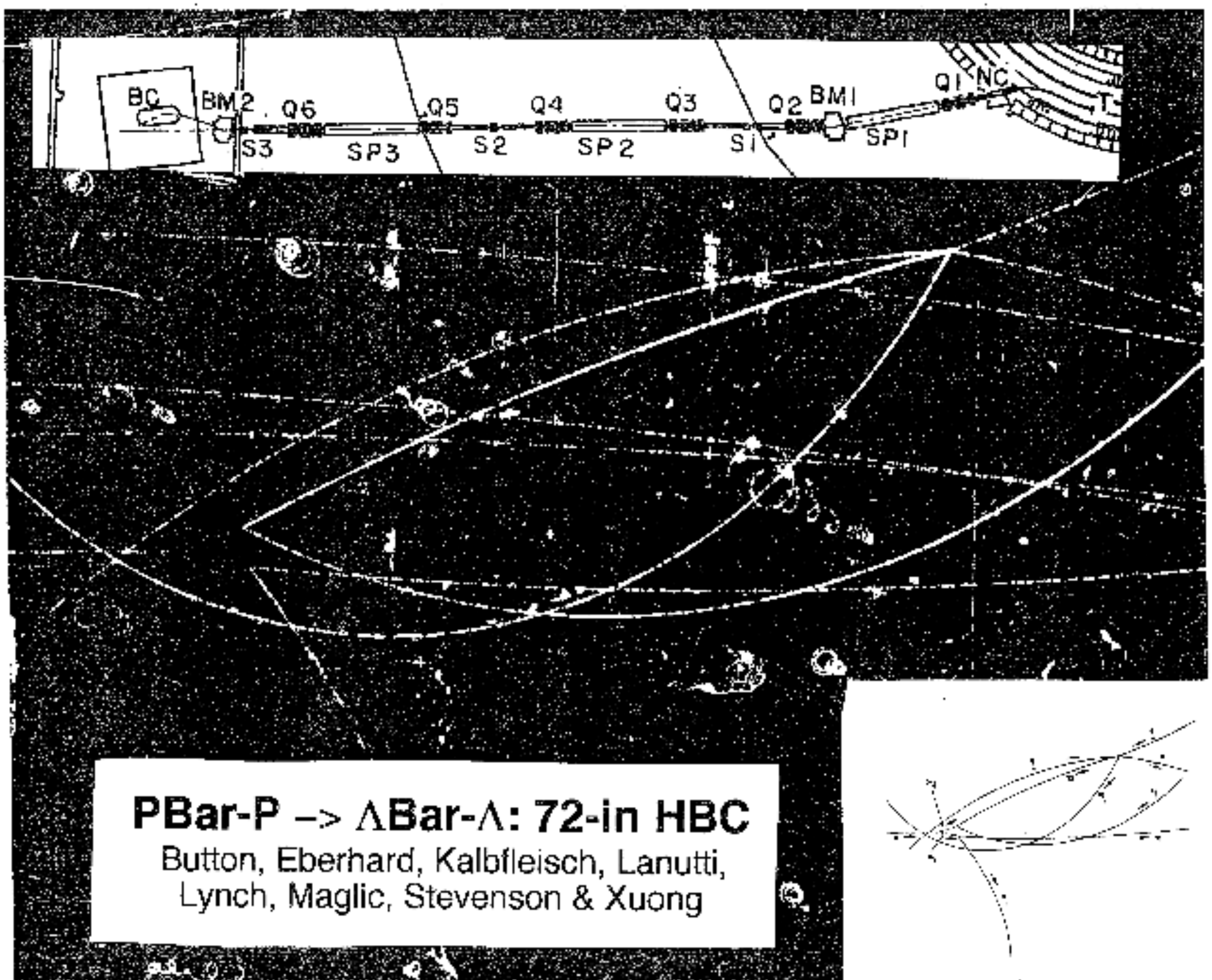




Armenteros, Coombes, Cork, Lambertson & Wenzel
Phys Rev 119, 2068 (1960)

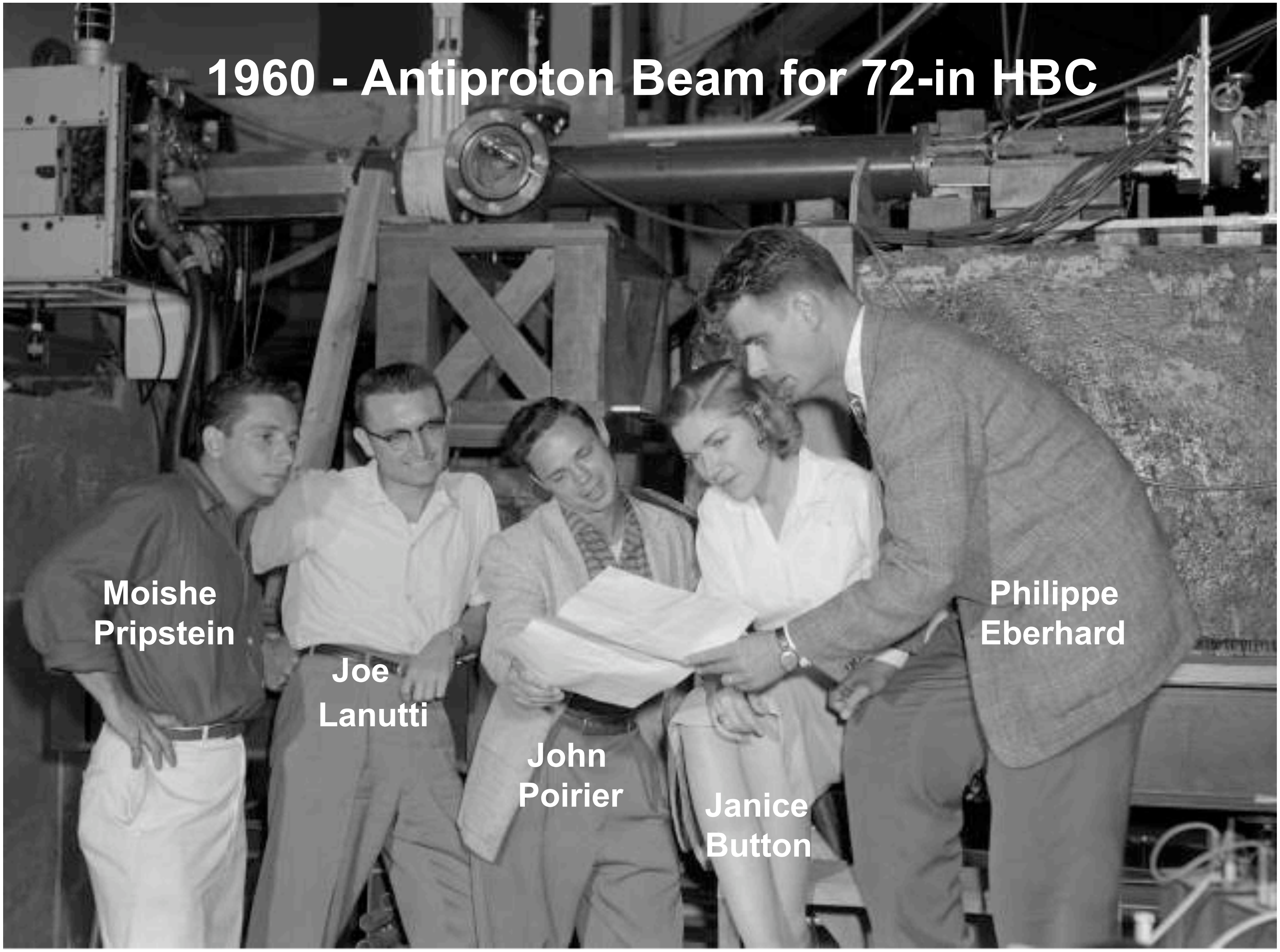


Elioff, Agnew, Chamberlain, Steiner, Wiegand & Ypsilantis
Armenteros, Coombes, Cork, Lambertson & Wenzel
Coombes, Cork, Galbraith, Lambertson & Wenzel
Cork, Lambertson, Piccioni & Wenzel
$\bar{p}-p$ total
p−p total
p−n total
$\bar{p}-p$ elastic
$\bar{p}-p$ charge exchange
Cross section (mb)
Antiproton kinetic energy (Bev)
0
0.4
0.8
1.2
1.6
2.0
2.4
40
80
120
160



PBar-P –> ΛBar-Λ: 72-in HBC

Button, Eberhard, Kalbfleisch, Lanutti, Lynch, Maglic, Stevenson & Xuong


1960 - Antiproton Beam for 72-in HBC
Moishe
Pripstein
Joe
Lanutti
John
Poirier
Janice
Button
Philippe
Eberhard